Analysis of a UHF Log-periodic Antenna

by Christopher Kenyon and Christian Fazi

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14. ABSTRACT

This investigation uses the method of moments (MoM) approach to model a 2:1 bandwidth UHF log-periodic antenna (LPA) with the emphasis on designing the best possible front-to-back (F/B) ratio, rather than maximum forward gain. The use of non-resonant parasitic elements embedded in the log periodic structure was investigated to determine its effect on broadband matching and the F/B ratio.

15. SUBJECT TERMS
log periodic antenna, LPA, front-to-back ratio, broadband matching, parasitic elements, MoM modeling

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Acknowledgments

1.   Introduction

A log-periodic antenna (LPA) is an array of half wavelength (or integer multiple) dipoles for which the input impedance and radiation patterns vary periodically with the logarithm of the frequency. These antennas are usually only linearly polarized. The design of broadband LPAs has been the subject of many investigations over the years. The use of the term "broadband" has been rather loose. It has been described to apply to antennas operating over a 3 to 1 ratio or more (even up to 10 to 1) bandwidth, though the patterns and impedance may vary widely over that range. The smaller the variation of the antenna characteristics over a frequency range, the more broadband the antenna is. These include the impedance, the gain, front-to-back (F/B) ratio, etc.

The geometric ratio of a LPA is given by the ratio of the lengths of the elements, the spacing and the diameter of the elements as shown in figure 1. The antenna's dimensions are provided in the appendix.
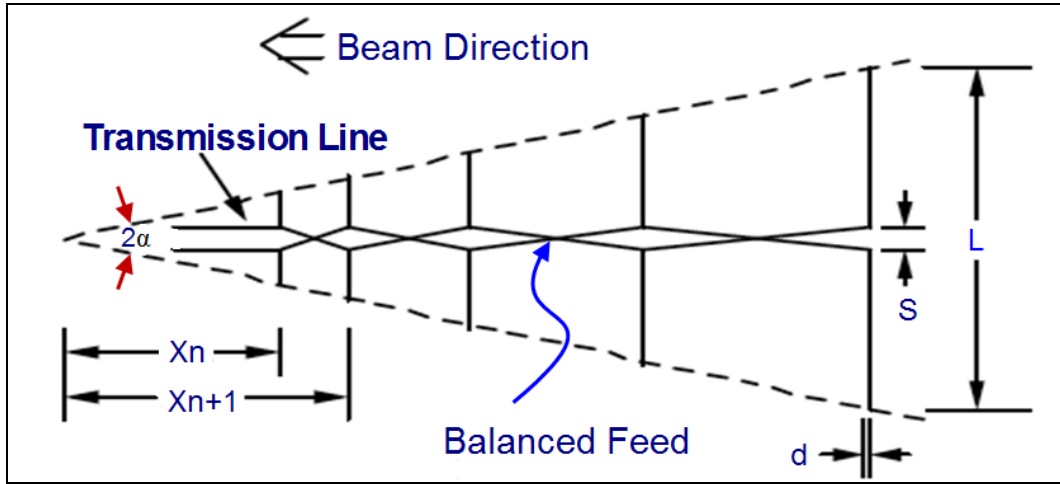

Figure 1. Schematic of a LPA.

In figure 1, L = element length, X = element spacing, S = transmission line gap, d = element diameter, fn = single element resonance frequency ($f_n > f_{n+1}$), 2α = full angle taper, $\tau = L_n/L_{n+1} = X_n/X_{n+1} = S_n/S_{n+1} = d_n/d_{n+1} = f_n/f_{n+1}$, $\sigma = (X_{n+1}-X_n)/(2L_{n+1})$, and $\alpha = \tan^{-1}[(1-\tau)/(4\sigma)]$. The separation between f_n and f_{n+1} is defined as the period of operation.

The 180° feed phase reversal of the elements produces a beam end-fire pattern that radiates in the direction of the shorter elements (the feed point). Only a few sets of adjacent dipole elements support large enough currents to radiate at any single frequency. The other elements are not active, hence, the relatively low gain properties of an LPA. Since the balanced feed line is truncated at both ends, this limits the useful bandwidth of operation. When the elements are orthogonal to the transmission line the coupling is based on a single resonance mode, typically

½ lambda. When tilted at an optimum angle, the elements can couple by higher modes such as ½, 3/2, and 5/2 lambda. Some broadband LPAs take advantage of this, allowing very high frequency (VHF) elements to couple into the ultra high frequency (UHF) band. This allows more elements to couple energy and increase the LPA gain.

2. Log Periodic Antenna with Non-resonant Parasitic Elements

The initial starting point for this investigation of matching and determination of impact on F/B ratio was a UHF LPA with added non-resonant elements. Such an antenna held a promise of a good F/B ratio of the directivity over a broad frequency band without being physically too large. Figure 2 shows a computer model of our optimized original antenna, antenna 1. This particular model was designed by optimizing rod positions and lengths for maximum F/B ratio and favorable S11 over about 200 to 500 MHz, subject to some constraints on total length and relative lengths of the elements. The simplex algorithm within the FEKO method-of-moments (MoM) software was the dominant optimizer used.
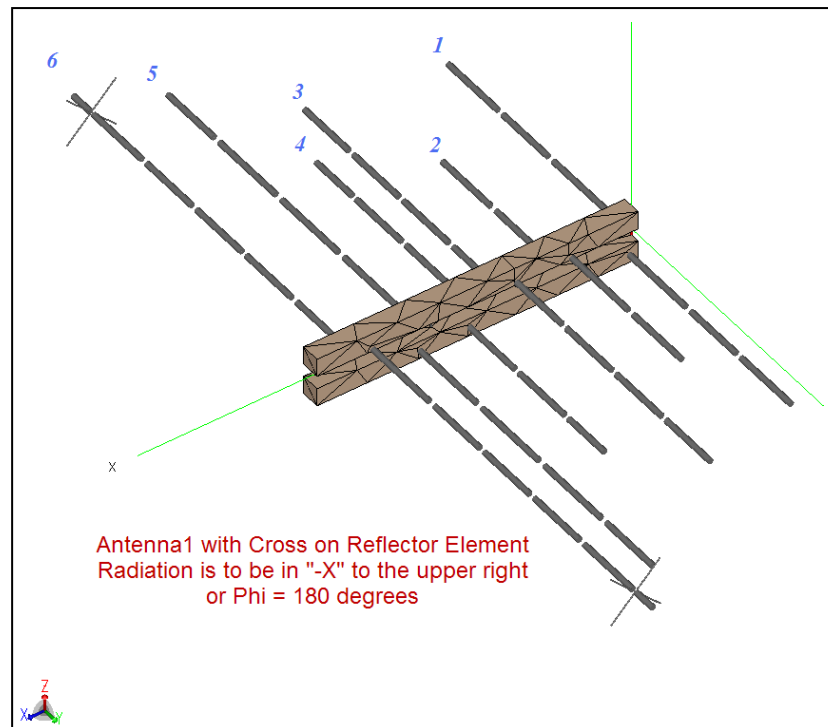

Figure 2. FEKO software drawing of computer facet model of antenna 1, LPA
with non-resonant elements (rod pair 2 and rod pair 4).

Figures 3 through 10 show the E- and H-plane gain patterns for our original antenna at 300 and 450 MHz calculated by FEKO and measured in our chamber. In all cases, the larger lobe is in the forward direction of the antenna. For consistency with graphs of the measured fields, the calculated fields have been plotted as though the antenna was pointed in the +x or φ = 0°

direction, where the φ, or azimuthal, direction is measured about the *z*-axis. In the E-plane patterns, the φ component of the gain is graphed against the φ, or azimuthal, direction and θ is 90°. The H-plane patterns consist of the θ component of the gain and are plotted versus the θ angle (90° elevation angle). Note that in the H-plane graphs of measured gain the antenna was aligned with θ = 0°, whereas in the FEKO calculations it was aimed at θ = 90°. The gain patterns calculated from the computer models are quite similar to the measured gain patterns of a physical antenna. The asymmetry in the measured gain shown in figures 4, 6, 8, and 10 was suggested[1] to be a result of undesired coupling between the feed line and the antenna. The measured F/B ratios can be seen to be stronger than the values calculated from the FEKO model.

Figures 11 and 12 show the FEKO calculated E-plane and H-plane front and back gains for this antenna. The H-plane front gain is roughly 20 dB below the E-plane front gain. Figure 13 shows calculated F/B (E-plane) gain ratio for this antenna. Figure 14 shows both the measured voltage standing wave ratio (VSWR) of the constructed antenna and the VSWR calculated from a FEKO model of it. Both curves rise up near 550 MHz and both are generally below 3 between 250 and 550 MHz. The FEKO calculated dips near 340, 460, and 520 MHz roughly mirror dips in the measured VSWR. Both the calculations and measurements indicate that this antenna has a reasonable VSWR for receiving.
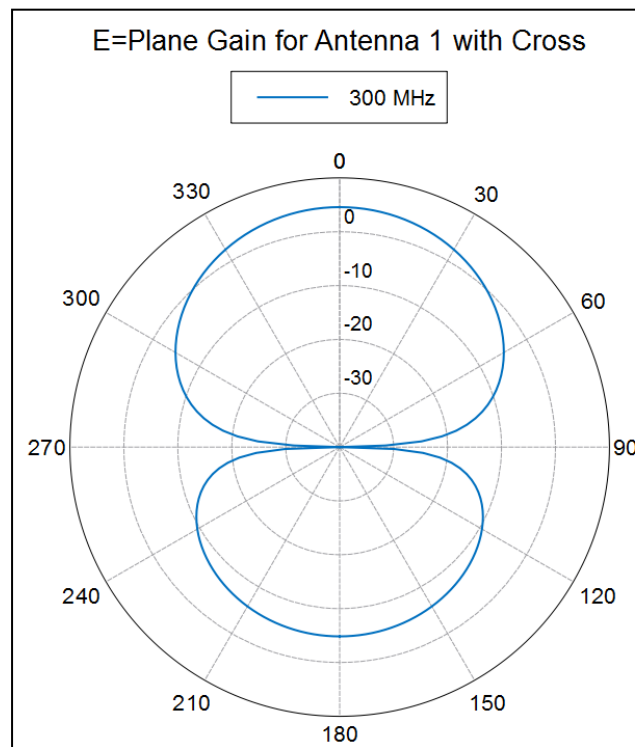

Figure 3. FEKO calculated E-plane gain for antenna 1 vs. azimuth angle, φ, at 300 MHz with θ = 90°. (The antenna is also pointed at θ = 90°.)

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[1] Ressler, M. U.S. Army Research Laboratory, Adelphi, MD. Personal communication, 2011.
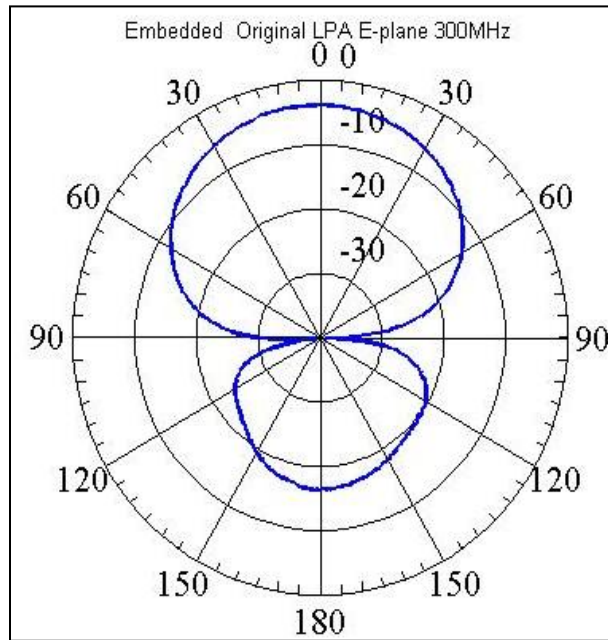
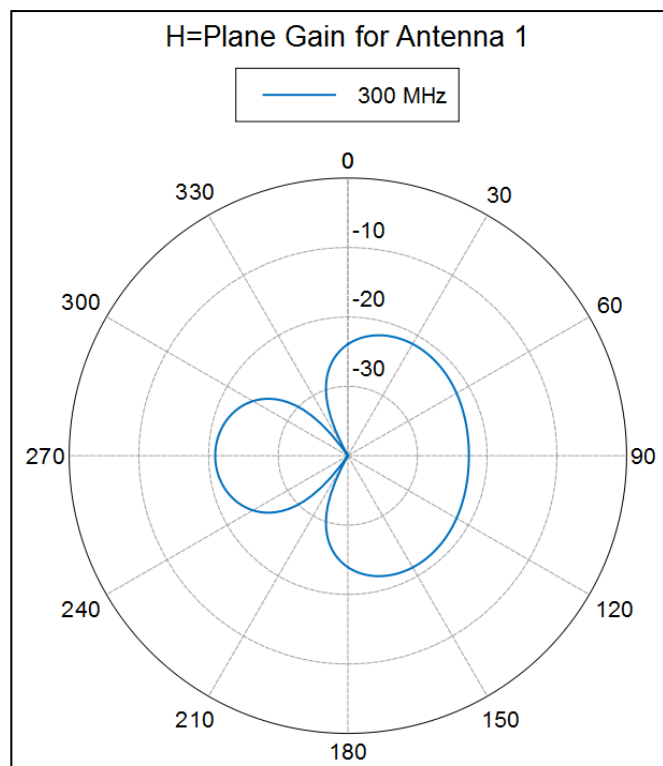Figure 4. Measured E-plane gain for antenna 1 vs. φ at 300 MHz.

Figure 5. FEKO calculated H-plane gain for antenna 1 vs. θ, at 300 MHz with antenna aimed at φ = 0° and θ = 90°.
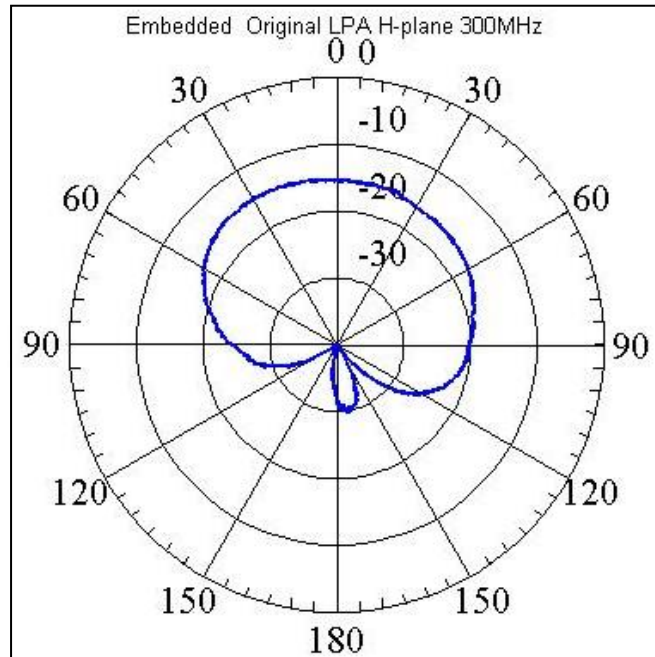
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Figure 6. Measured H-plane gain for antenna 1 vs. θ at 300 MHz
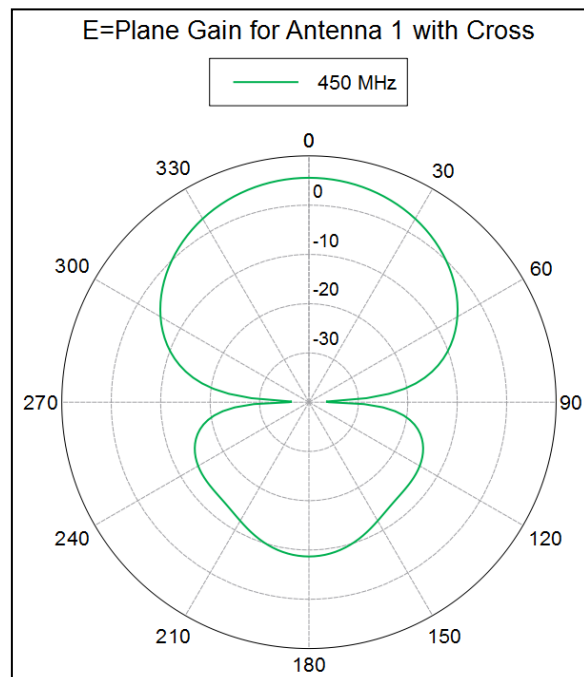with antenna aimed at 0° in this graph.

Figure 7. FEKO calculated E-plane gain for antenna 1 vs.
azimuth angle, φ, at 450 MHz with antenna aimed
at φ = 0° with θ = 90°.

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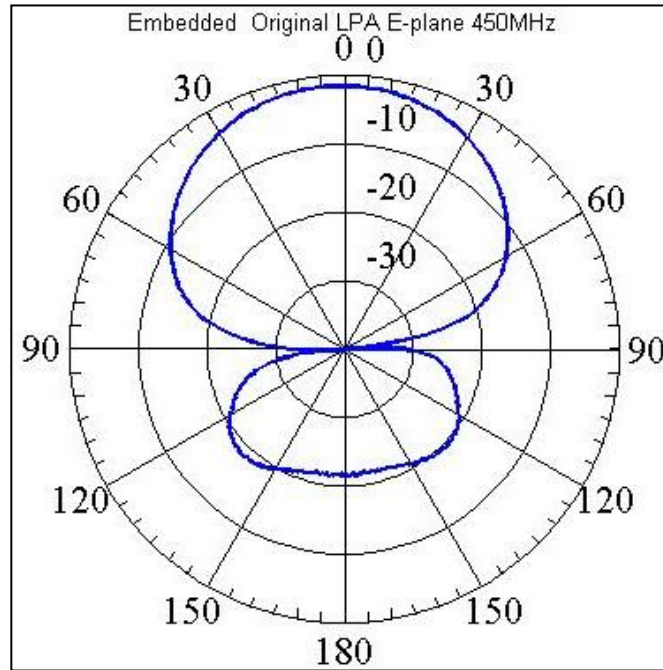
Figure 8. Measured E-plane gain for antenna 1 vs. φ at 450 MHz.
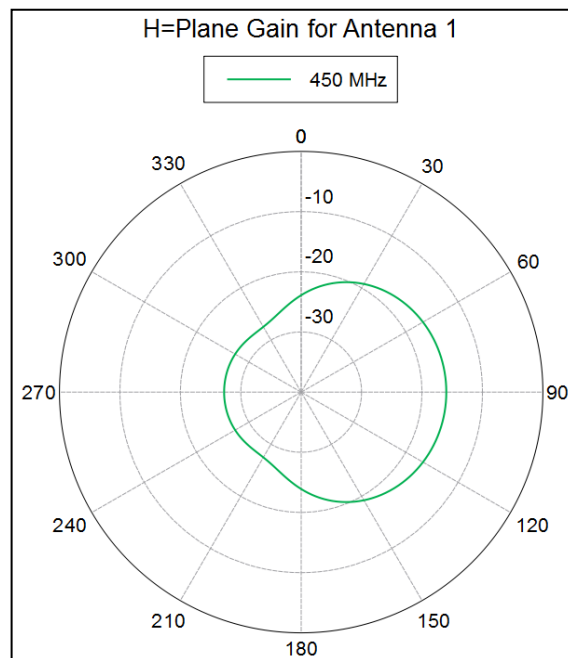The antenna is aimed at θ = 90° and φ = 0° in this graph.

Figure 9. FEKO calculated H-plane gain for antenna 1 vs. θ, at
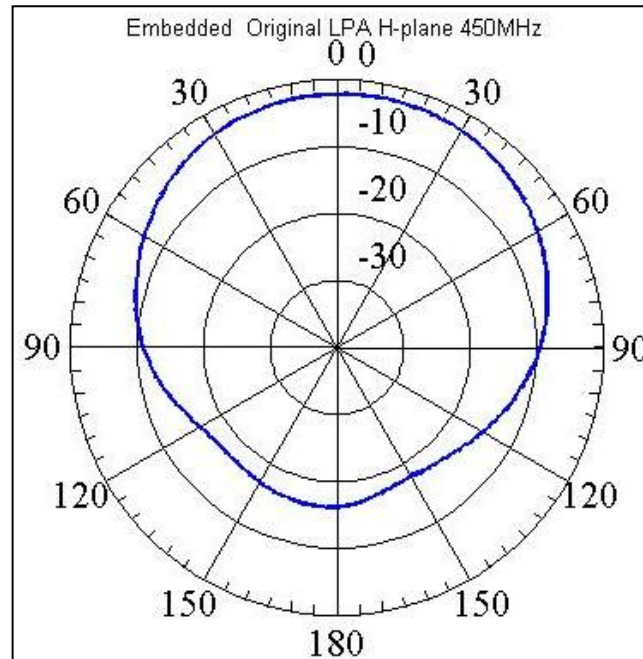450 MHz with antenna aimed at φ = 0° and θ = 90°.

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Figure 10. Measured H-plane gain for antenna 1 vs. θ at 450 MHz.
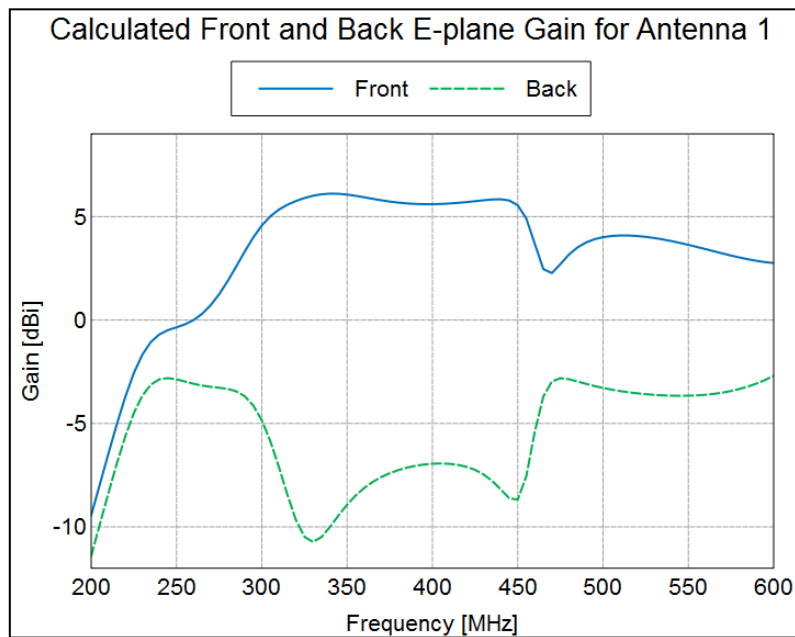The antenna is aimed at θ = 0° in this graph.

Figure 11. FEKO calculated front and back gain for antenna 1.
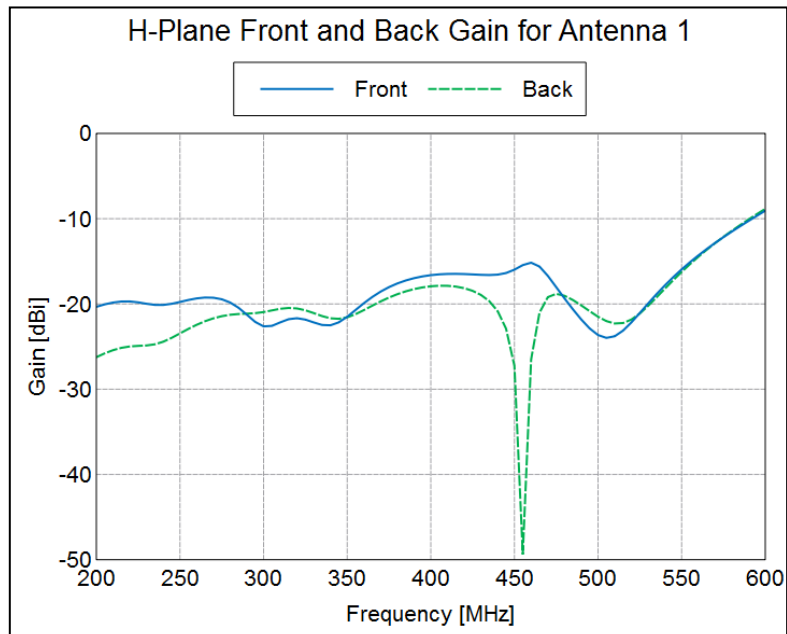
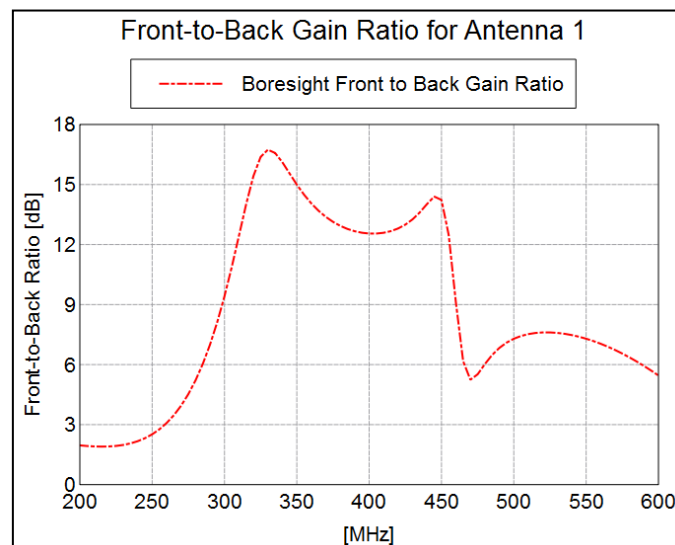Figure 12. FEKO calculated H-plane front and back gain for antenna 1.

Figure 13. Calculated front to back E-plane gain ratio for the FEKO
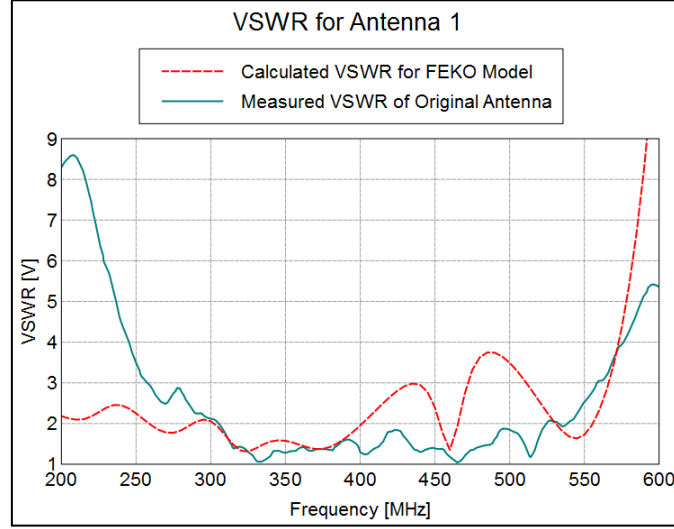model of antenna 1.

Figure 14. Measured VSWR for antenna 1 and calculated VSWR
from FEKO model referenced to 50 Ω.

3. A Conventional UHF Log Periodic Antenna

While the measured characteristics of the LPA with non-resonant parasitic elements has a favorable F/B directivity ratio, we also compare to a conventional LPA design (as shown in figure 1). Balanis[2] gives some guidance on maximizing directivity and performance. The antenna was designed over the 250 to 500 MHz band, with the intent of minimizing its dimensions.

Computed contours of constant directivity versus the LPA parameters, σ and τ, defined in the introduction are shown in Balanis's Antenna Theory[2]. A Balanis Matlab program[2] was used with FEKO to evaluate several σ-τ combinations to see where a favorable F/B gain might occur within the σ-τ space of their figure 11.13. The Matlab program calculates F/B ratio based on desired directivity for an idealized model. Antenna element length and separations or τ and σ from favorable F/B ratios from these calculations served as starting points for accurate FEKO models of our antenna. Preliminary calculations indicate that the locus of our favorable σ-τ combinations that yields a high directivity appear to also give the best F/B ratio for an LPA. Another constraint is that the size of the antenna not be too large. Since higher σ's and τ's result in a longer antenna, we avoided those regions.

Figures 15 and 16 show both the FEKO model resulting from our optimization search over favorable LPAs and the calculated current distributions at 300 and 450 MHz. Figures 17 and 18 show the calculated E- and H-plane field patterns at 300, 375, and 450 MHz. Figures 19 and 20 show the calculated tboresight front and rear gain, while figure 21 shows the resulting F/B ratio

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[2] Balanis, C. A., *Antenna Theory*, 3rd ed.; Wiley: Hoboken City, NJ, 2005.

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with frequency. Figure 22 shows the VSWR calculated for this LPA is mostly below 3 so that its impedance is reasonably well matched to 50 Ω. With its good gain and low VSWR, the antenna can radiate well within the band of interest.
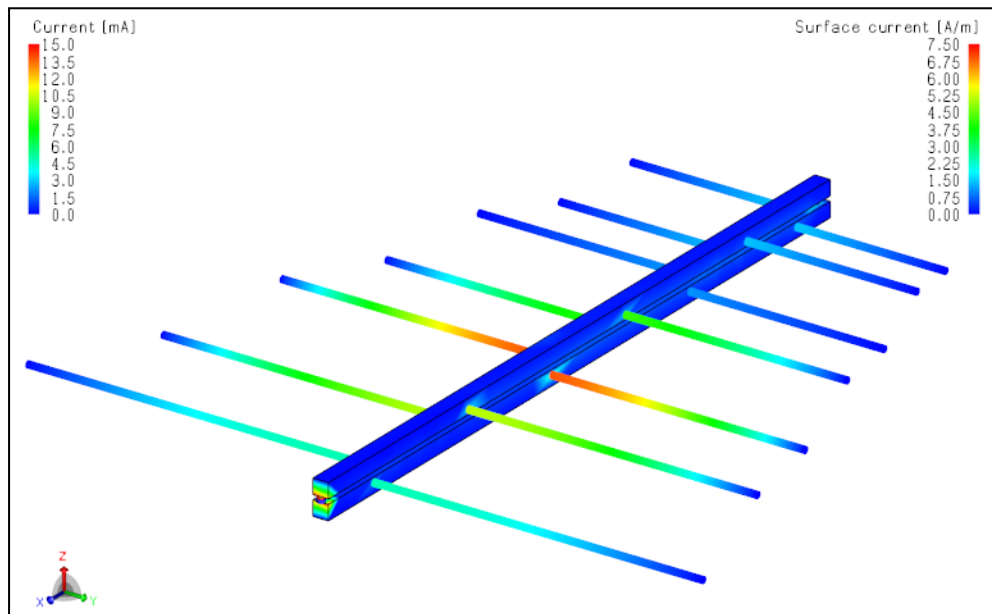

Figure 15.   Optimized LPA antenna showing MoM computed current distributions over facets at 300 MHz.
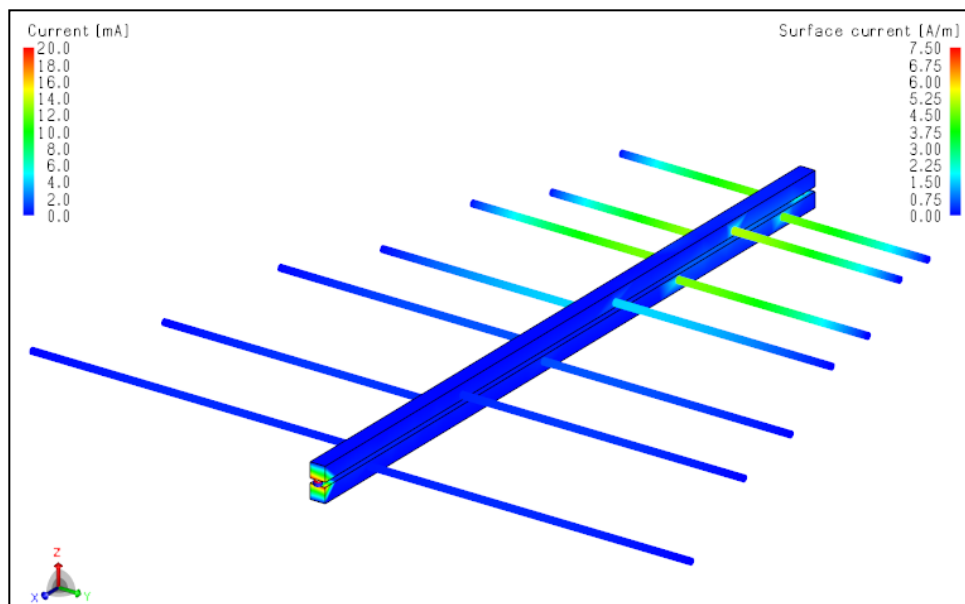

Figure 16. MoM computed currents at 450 MHz.

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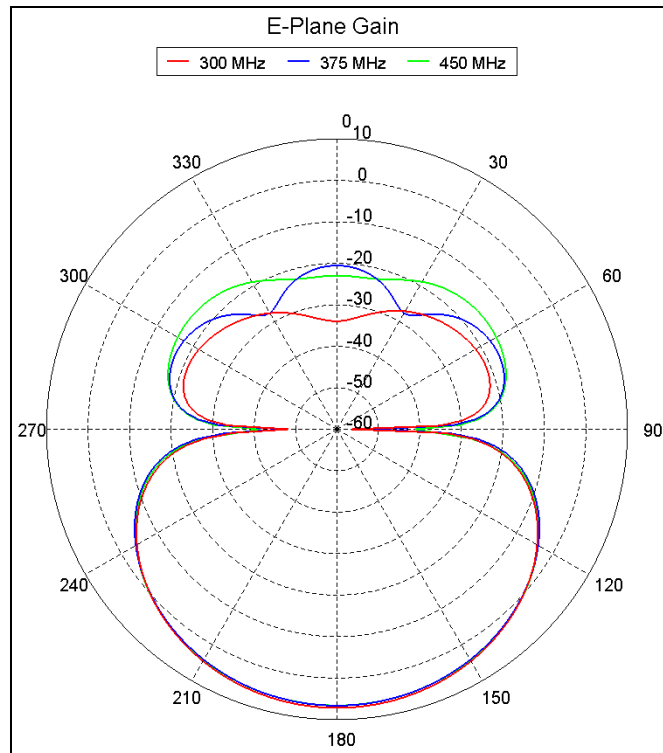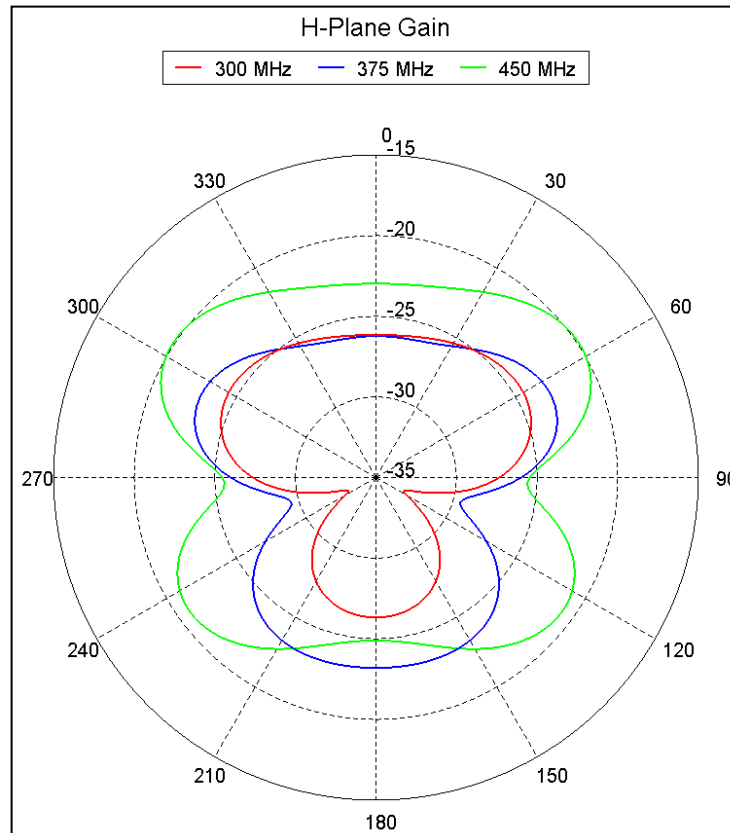Figure 17. FEKO standard LPA model calculated E-plane gain.

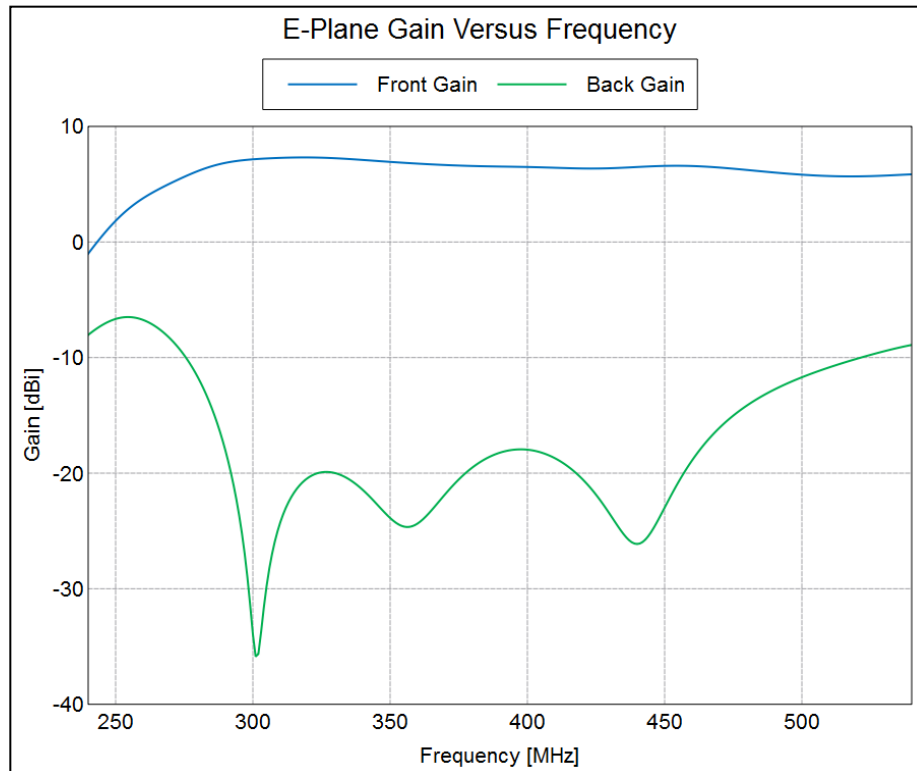Figure 18. FEKO model calculated H-plane gain.

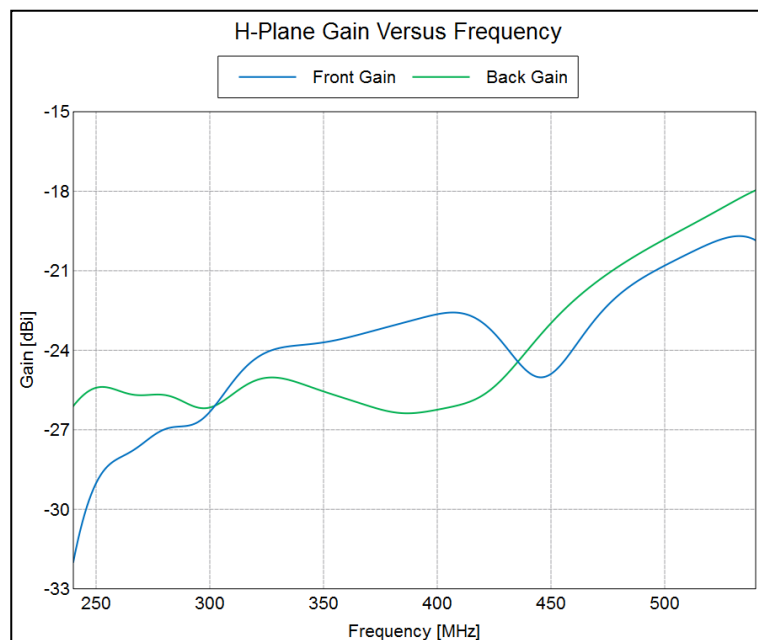Figure 19. FEKO calculated boresight E-plane gain for standard LPA.

Figure 20. FEKO LPA model calculated boresight H-plane gain for standard LPA.
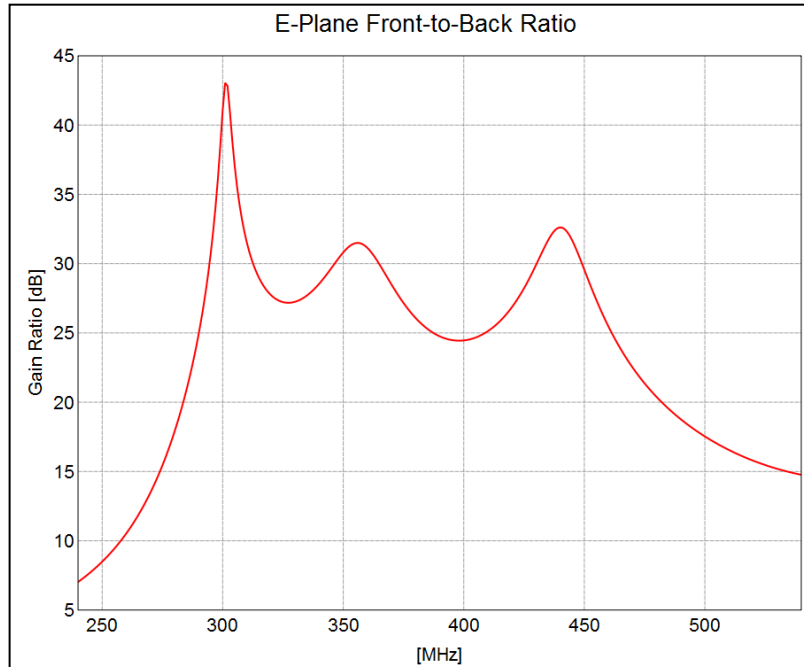
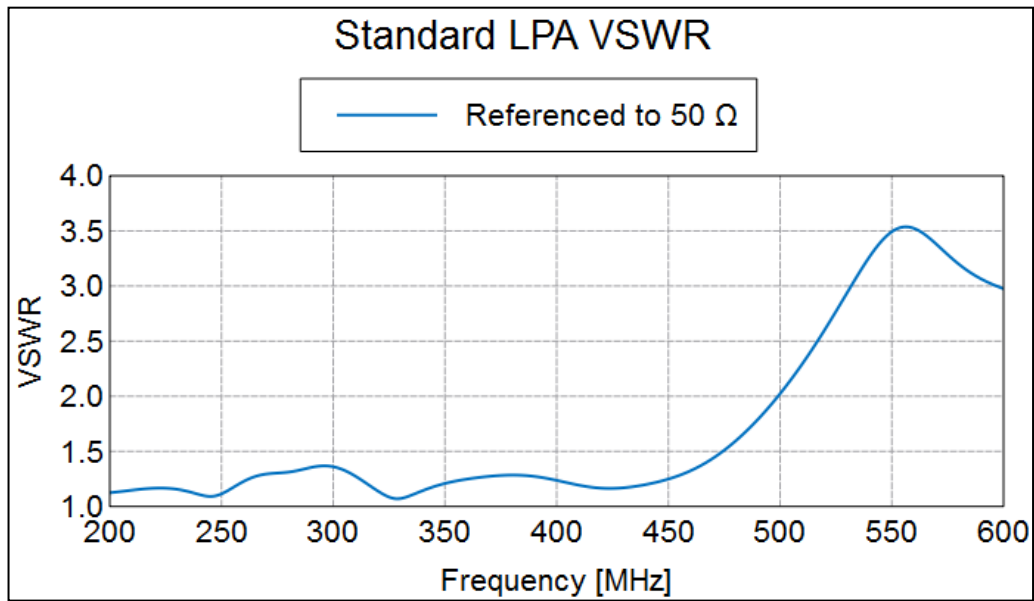Figure 21. FEKO calculated LPA model E-plane F/B gain ratio for our standard LPA.

Figure 22. Computed VSWR for FEKO LPA model with 50 Ω input impedance.

4. Conclusions

Both the original LPA with the parasitic elements and the simpler LPA have favorable F/B ratios of 10 dB or better within about 300 to 450 MHz and, therefore, satisfy our needs. In both kinds of antennas, the E-plane gains are roughly 20 dB above the H-plane gains, indicating little coupling into the opposing polarization. This may indicate that an interleaved antenna with horizontal and vertical linear polarization is possible.[1] Characteristics of original LPA with the parasitic elements are confirmed with both the modeling and the measurements. This antenna also appears to show better VSWR between 500 and 550 MHz than our standard LPA according to the FEKO calculations.

However, the standard LPA has a much more uniform forward gain over 300 to 500 MHz and a higher F/B ratio by about 10 dB over our original LPA from, at least, the range of 300–500 MHz. Therefore, the standard LPA performs better. However, it is about 60 cm long while the LPA with the parasitic elements is only about 20 cm long. Thus, if size is a very important factor, the latter would appear to be the preferred antenna; otherwise, the standard LPA would be preferred.

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Appendix. Antenna Dimensions

Figure A-1 of antenna 1, along with table A-1, shows the length and placement of rod elements in its antenna. Figure 24 within the report shows the dimensions of its transmission line. The physical antenna used a 33-Ω termination resistor, though FEKO calculations indicated that it performed well with that resistance value.
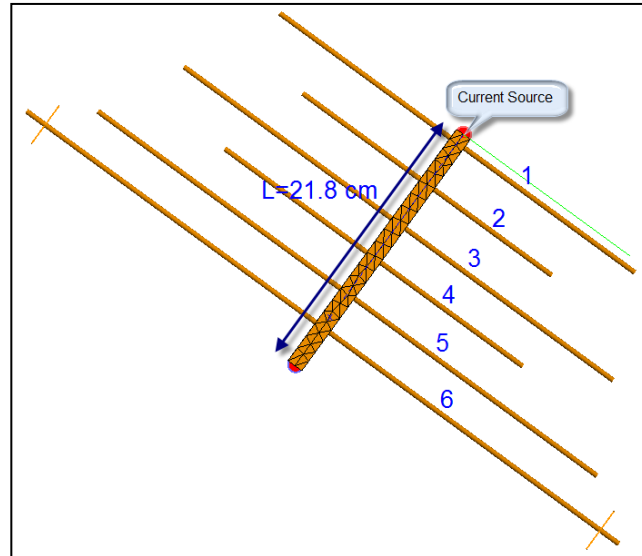

Figure A-1. FEKO model of LPA with parasitic elements (elements 4, 2).
The four cross elements near the rod ends are 1.8 cm long each.

Table A-1. Rod element parameters for antenna 1.

Rod Pair	Distance from Antenna End (cm)	Rod Length (cm) (from transmission line)
1	0.8	16.1
2	4.7	11.1
3	8.4	19.6
4	11.6	13.4
5	15	22.9
6	18.2	27.3

Figure A-2, along with table A-2, shows the dimensions of our standard or traditional LPA, including rod element placement and length. LPA transmission line pieces had the same width and height as did those for antenna 1, but separation between the two pieces was only 0.4 cm. The antenna was predicted to perform well with a 50-Ω termination as shown.
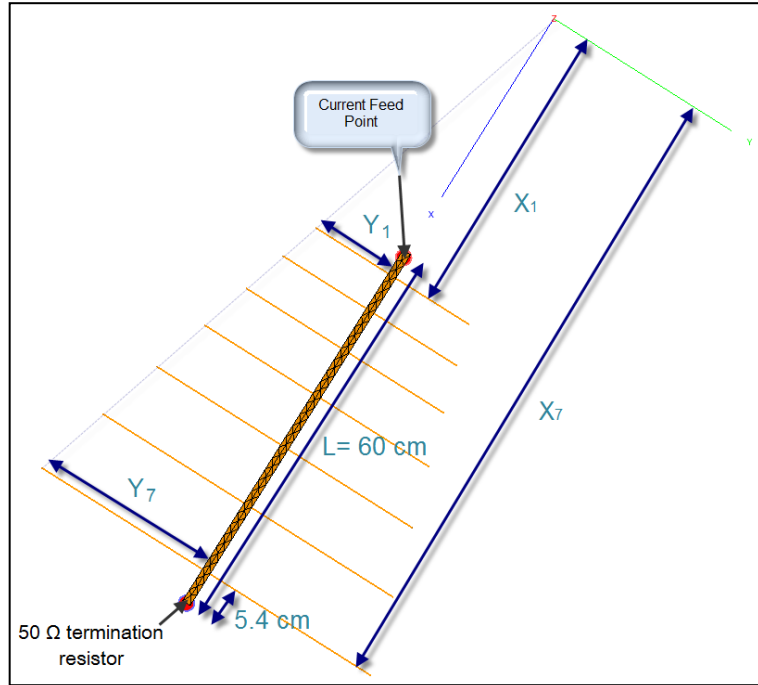
Figure A-2. Our standard LPA, top view, with design dimensions.

Table A-2. Rod parameters for our standard LPA.

Rod Pair		Distance from Apex (cm)	Distance from Antenna End (cm)		Rod Length (cm)
1	X_1	44.0	4.0	Y_1	12.5
2	X_2	50.0	10.0	Y_2	14.3
3	X_3	56.8	16.8	Y_3	16.4
4	X_4	64.5	24.5	Y_4	18.7
5	X_5	73.3	33.3	Y_5	21.3
6	X_6	83.3	43.3	Y_6	24.3
7	X_7	94.6	54.6	Y_7	27.7

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